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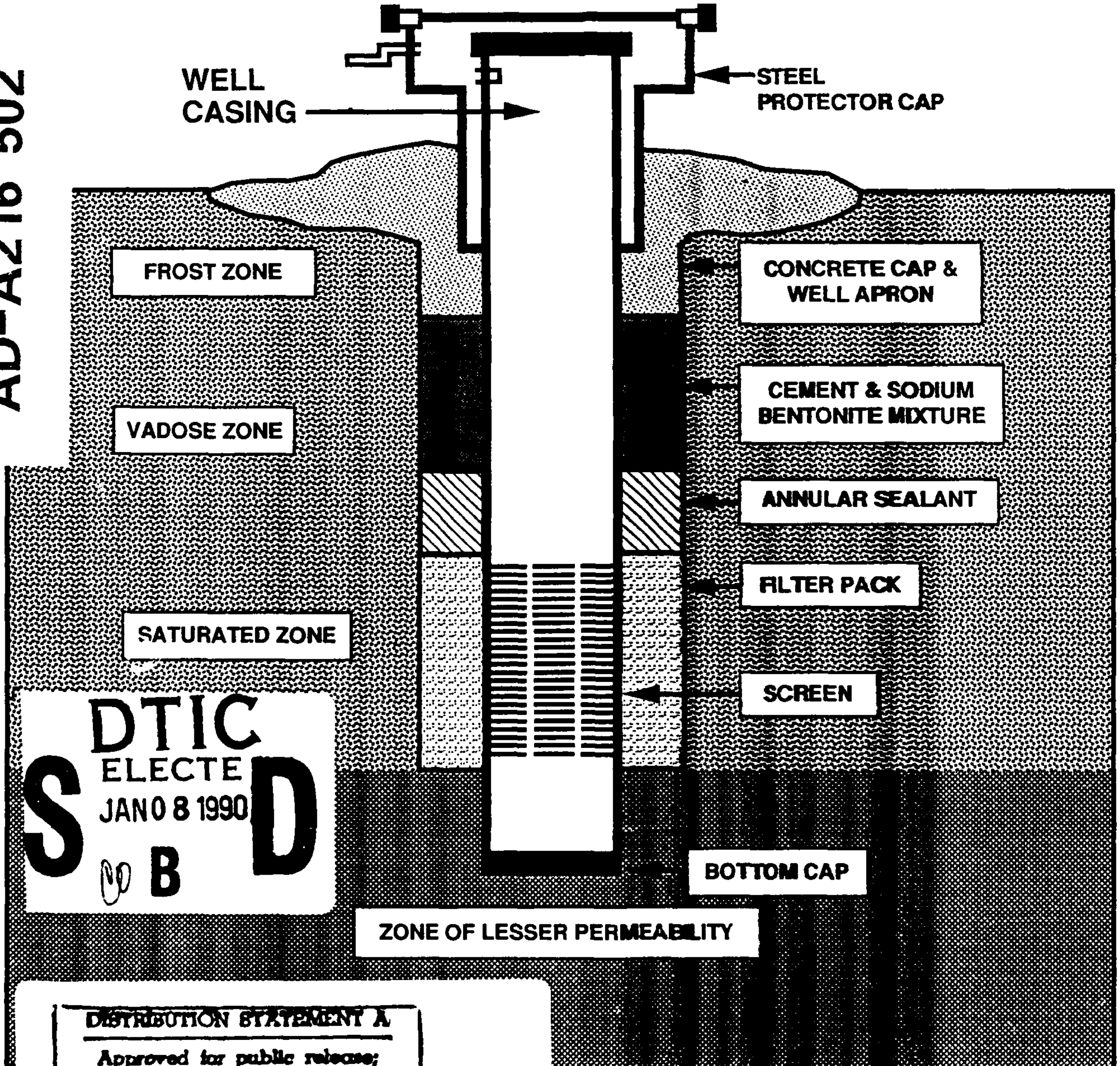
Evaluation of four well casing materials for monitoring selected trace level organics in ground water



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October 1989

Evaluation of four well casing materials for monitoring selected trace level organics in ground water

Louise V. Parker, Thomas F. Jenkins and Patrick B. Black

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In this study we examined four well casing materials, polyvinyl chloride (PVC), Teflon, stainless steel 304 (SS 304) and stainless steel 316 (SS 316), to determine their suitability for monitoring selected trace level organic constituents in ground water. Analyte solutions containing pieces of the different well casings were compared to controls that did not contain any well casing material. The aqueous test solution contained approximately 2 mg/L of each of the following organic substances: hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), trinitrobenzene (TNB), cis- and trans-1,2-dichloroethylene (CDCE and TDCE), m-nitrotoluene (MNT), trichloroethylene (TCE), chlorobenzene (CLB), and o-, p-, and m-dichlorobenzene (ODCB, PDCB, and MDCB). Mercuric chloride was added to prevent biodegradation of the analytes. The two sets of isomers for DCE and DCB were selected to examine the effect of structure on sorption. Samples were taken after 0 hour, 1 hour, 8 hours, 24 hours, 72 hours, 7 days (168 hours), and approximately 6 weeks (1000 hours). There was no loss of any analyte in the samples that contained either type of stainless steel casing, although both types of casing rusted. The greatest losses were seen in samples that contained Teflon casings, especially for the chlorinated organics. Losses of PDCB and MDCB were the greatest, 16% and 18%, respectively, after only 8 hours. While losses were also observed for the samples containing PVC casing, the rate of loss was much –

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slower, and usually 24 hours or more elapsed before losses were significant (more than 5%). After the 1000-hour samples were taken, the casings were rinsed and placed in clean vials containing fresh water and left for three days to allow for desorption. From both plastic casings we recovered measurable quantities of all the organics that had been lost from solution. We were able to correlate the loss of hydrophobic organic constituents in the ground water containing the Teflon casings with the substance's octanol-water partition coefficients, although this correlation overestimates losses of hydrophilic organics. Our results indicate that Teflon casings are probably not suitable for monitoring trace level organics. For wells that are purged and sampled within an 8- to 24-hour period, PVC well casings probably are suitable for monitoring trace level organics.

PREFACE

This report was prepared by Louise V. Parker, Research Physical Scientist, Applied Research Branch, Experimental Engineering Division, and by Thomas F. Jenkins, Research Chemist, and Dr. Patrick B. Black, Research Physical Scientist, both of the Geochemical Sciences Branch, Research Division, U.S. Army Cold Regions Research and Engineering Laboratory.

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Evaluation of Four Well Casing Materials for Monitoring Selected Trace Level Organics in Ground Water

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INTRODUCTION

Background

Several different materials have been used in the manufacture of well casings and screens for monitoring ground water. These materials include virgin fluorocarbon resins, i.e., fluorinated ethylene propylene (FEP), polytetrafluoroethylene (PTFE and Teflon [R]), and stainless steel (304, 316, or 2205), cast iron, galvanized steel, polyvinyl chloride (PVC), polyethylene (PE), epoxy bisphenol and polypropylene (PP) (U.S. EPA 1986). Until relatively recently (1985) PVC was the preferred casing material. However, in 1985 the initial draft of the U.S. EPA's "Resource Conservation and Recovery Act (RCRA) Ground-Water Monitoring Technical Enforcement Guidance Document" was published. This document stated, "in constructing wells, the owner/operator should use Teflon, Stainless Steel 316, or other proven chemically and physically stable materials."

The EPA's concern was that many of the materials commonly used in ground water monitoring affected the quality of the samples or did not have the long-term structural characteristics required of RCRA monitoring wells. The EPA document stated that "steel casings deteriorated in corrosive environments; PVC deteriorated in contact with ketones, esters and aromatic hydrocarbons; polyethylene deteriorated in contact with aromatic and halogenated hydrocarbons; and polypropylene deteriorated in contact with oxidizing acids, aliphatic hydrocarbons and aromatic hydrocarbons." The EPA was also concerned that steel, PVC, polyethylene and polypropylene might adsorb or leach constituents, thereby affecting the composition of the ground water samples.

Because of the furor that followed publication of the initial draft of this document, the requirement was reduced slightly in the final version. This version stated that "fluorocarbon resins or stainless steel should be specified for use in the saturated zone when volatile organics are to be determined, or may be tested, during a 30-year period" (U.S. EPA 1986). The RCRA document further stated that "National Sanitation Foundation (NSF) or ASTM-approved polyvinyl chloride (PVC) well casing and screens may be appropriate if only trace metals or nonvolatile organics are the contaminants anticipated."

It is generally recognized that metal pipes can corrode, that polymeric materials such as PVC, PE and PP can soften and swell in the presence of either pure or highly concentrated solutions of some organic solvents, and that fluoropolymers are resistant to attack by almost all chemical species. However, in ground water monitoring situations very high concentrations or neat solvents are usually not encountered. Therefore, PVC casings may be suitable for monitoring organics in the concentration range most commonly found. This report focuses on the interactions between well casings (PVC, PTFE and stainless steel) and trace level organic constituents.

Literature review

Ideally the long-term interaction between a well casing and the ground water being monitored should not result in gain or loss of analyte or interference with the analytical method used for determination. Analyte loss can result from sorption of analyte by the casing material, from chemical or microbiological destruction of the analyte as a result of interaction with the surface, or leaching of a substance from the casing material.

Masse et al. (1981) outlined the factors involved in sorptive losses of metals on containers:

1. The chemical nature of the analyte and its concentration.

2. The characteristics of the solution—the pres-

ence of acids, dissolved material, complexing agents, dissolved gases (especially oxygen), suspended matter, and microorganisms.

3. The properties of the container—chemical composition, surface roughness, surface cleanliness, relative surface area, history (i.e., age, prior cleaning, and previous exposure).

4. External factors—temperature, contact time, access of light, and agitation.

These factors are generally applicable to well casing materials, and many of them are also applicable when considering the sorption of organics from solution.

There have been several studies examining the sorption of organics by rigid PVC. Lawrence and Tosine (1976) found that PVC chips were quite efficient in adsorbing PCBs from water and wastewater. However, PVC appeared to be effective only at sorbing PCBs when their concentrations were close to their solubility limit [illegible]

Pettyjohn et al. (1981) claimed that metal surfaces can also strongly adsorb organic compounds. Although they did not present any supporting data, they claimed that, for example, DDT [illegible] strongly adsorbed by stainless [illegible]

Miller (1982) conducted a six-week laboratory study that tested three types of well casing materials, including schedule 40 PVC, for sorption of trace levels (2–14 µg/L) of six volatile organics. The substances tested were bromoform, trichlorofluoromethane, trichloroethylene, 1,1,1-trichloroethane, 1,1,2-trichloroethane, and tetrachloroethylene. While the data he presented were only semiquantitative, tetrachloroethylene appeared to be sorbed by the PVC casing material (25 to [illegible] loss after six weeks). It is not clear [illegible] pound was preferentially sorbed [illegible]

[illegible]

had on the composition of sampled water. These wells had been in the ground for two years. Each well was only sampled twice. Although they found that concentrations of dissolved organic carbon and total organic carbon were 10% higher in the PVC well than in the steel well, the PVC casing was joined using organic solvents, which may explain the elevated organic carbon content. Perhaps their most significant finding was that sampling methods had a greater effect on the ground water composition than the type of casing.

Our laboratory studied the suitability of PVC well casings for monitoring low levels of military munitions and their breakdown products (Parker and Jenkins 1986). Specifically, the substances studied were 2,4,6-trinitrotoluene (TNT), hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), and [illegible] dinitrotoluene (DNT). Our initial study, conducted for 80 days under non-sterile conditions, indicated significant loss of TNT and to a lesser extent HMX in the presence of PVC well casing [illegible] day follow-up study, conducted using both sterile and nonsterile conditions [illegible] seemed to be [illegible]

[illegible]

Reynolds and Gillham [illegible] perhaps the most [illegible] PTFE materials to [illegible] determine the sorption [illegible]

[illegible]

(1986) determined the time at which the relative concentration (C/C_0) was reduced to 0.9 for each polymer and then ranked them in order. The order the compounds were sorbed varied between polymers. Reynolds and Gilham (1986) compared this order of loss with the compounds' octanol/water partition coefficient (log K_{ow}), undecane/water partition coefficient, and solubility in water, but they did not find any relationship (Table A1).

They attributed the loss by the polymer materials to absorption. They developed a model where uptake of an organic compound first proceeds by sorption/dissolution into the polymer surface, followed by diffusion into the polymer matrix. Their analytical model is given in eq 1:

$$\frac{C}{C_0} = \exp\left[\frac{KDt}{A^2}\right] \operatorname{erfc}\left[\frac{(KD)^{1/2}\ t^{1/2}}{A}\right] \qquad (1)$$

where C = concentration in solution (µg/L) at time t (sec)

C_0 = initial solution concentration (µg/L)

C/C_0 = relative concentration (dimensionless)

K = partition coefficient between the organic compound in solution and the polymer (dimensionless)

D = diffusion coefficient in the polymer (cm^2/sec).

The product of K and D is defined as the permeability coefficient (P).

Using this model, Reynolds and Gillham (1986) fitted curves through the data and found reasonable agreement between eq 1 and most of their experimental results. They were unable to fit a curve through the data for absorption of bromoform by PTFE or 1,1,1-trichloroethane by PVC, because they did not measure any absorption of these compounds after five weeks. They also found that after three weeks hexachloroethane and bromoform were more rapidly absorbed by PVC than eq 1 predicted. However, enhanced biodegradation in the presence of PVC (similar to what Parker and Jenkins [1986] observed with nitroaromatics) could also explain this additional loss. They noted additional peaks in the chromatograms of these samples; these peaks were similar to ones they had observed in degraded stock solutions of bromoform and hexachloroethane. No precautions were taken in their study to prevent biodegradation of the analytes.

Reynolds and Gillham (1986) felt that their results for PVC compared well with those from Miller (1982), except for the results for bromoform with PVC. Miller noted no loss after six weeks, whereas they found 43% loss after five weeks.

Reynolds and Gillham (1986) concluded that PVC absorption was sufficiently slow so that any resulting bias would most likely not be significant for these compounds, provided the well is developed and sampled on the same day. They also concluded that the same was true with PTFE except for tetrachloroethylene. However, they did not feel they had sufficient data to recommend the use of PVC over PTFE, and they also could not predict which organic chemicals were most susceptible to absorption. Moreover, we feel that some caution should be used when extrapolating their data since they did not use actual well casings.

Sykes et al. (1986) evaluated sorptive losses of organics by well casing materials in a laboratory study that may more closely parallel a real ground water monitoring situation. Control samples, which contained only the aqueous organic solution, were compared with samples that also contained either pieces of PVC, stainless steel or PTFE well casing. The organics tested were methylene chloride, 1,2-dichloroethane, trans-1,2-dichloroethylene, trichloroethylene, toluene, and chlorobenzene. Concentrations ranged from 87 to 150 µg/L. After seven days at 5°C, solutions were decanted and replaced with fresh solution (at the initial concentrations). Samples were then taken after 1 hour, the sample solutions were again refreshed, and final samples were taken after 24 hours. They reported that for both exposure times and all organics tested, the mean values for the solutions exposed to casing materials (three replicate samples) were usually within 1 standard deviation of the mean control values (nine replicate samples). They concluded that there were no statistically significant differences between the control samples and those containing well casings.

Barcelona and Helfrich (1986) conducted an in-situ study to determine the effect of well construction material on the reliability of determinations of organic chemical constituents in ground water. They constructed adjacent wells at upgradient and downgradient locations at two sanitary landfill sites. Casing materials were PTFE, 304 stainless steel, and PVC. No solvent cements, threaded joints, or uncommon materials were employed in well construction. Their findings are based on samples taken once a month for 6 months.

At site 1 Barcelona and Helfrich (1986) generally found, at the downgradient location, higher levels of total organic carbon content (TOC) in samples from the stainless steel and Teflon wells than from the PVC well. The levels of 1,1-dichloroethane (DCE) were generally higher in samples taken from the downgradient Teflon and stainless steel wells than those taken from the PVC well. The values for cis-1,2-dichloroethylene (CDCE) were considerably higher in the samples taken from the stainless steel well than in those from either plastic-lined well.

At site 2, the levels of DCE were 10 times higher than at site 1. In contrast to site 1, the levels of purgeable organics were consistently higher for the PVC well samples than for the stainless steel or Teflon samples. The concentration of DCE was two times greater for the samples from the PVC well than for those from the stainless steel well. Because these wells were only about 1 m apart, Barcelona and Helfrich felt it unlikely that they had intercepted ground water of different microconstituent quality. However, while they concluded that well casing materials exerted significant, though unpredictable, effects on the determination of total organic carbon and specific volatile organic compounds, we feel a much larger statistical base than two data sets is needed before any conclusions of this type can be drawn. Also, other differences in the construction of the wells may be responsible for these differences.

Gossett and Hegg (1987) compared three sampling devices, including a handmade Teflon bailer and a PVC bailer, to determine their effects on the recovery of three volatile organic compounds in ground water. The three organics used were chloroform, benzene and 1,2-dichloroethane; the initial concentrations were 749, 439 and 628 mg/L, respectively. They used two experimental wells: one constructed with PVC casing and the other with stainless steel. Based on analysis of variance, they claimed that neither sampler type nor well casing material had a significant effect. However, with only one sampler of each type of material and no report of the number of replicate samples, we caution against extrapolating these results to a larger population of samplers or casings.

In a laboratory study, Jones and Miller (1988) examined several different well casing materials for sorption of several trace level (parts per billion) organic constituents. The materials included PVC, ABS, Teflon, stainless steel 304, and Kynar (polyvinylidene fluoride or PVDV). Although they found losses for most of the compounds tested, there were no control samples that could be used for comparison. Therefore, losses could result from sorption by the glass containers or Teflon caps, or from chemical degradation or biodegradation since no precautions were taken to prevent biodegradation.

Aside from possible losses due to sorption, casings may leach substances that could interfere with analyses or could cause, or aid in, alteration of the analyte in question.

Several components of rigid PVC may possibly leach. These components include vinyl chloride monomer (VCM), thermal stabilizers, pigments, lubricants, fillers, impurities, and transformation products. While older studies (Banzer 1977 and Dressman and McFarren 1978) found that significant concentrations of VCM leached from PVC pipe into water, this problem has been greatly moderated by reducing the residual VCM levels in the resin and finished products (Barcelona et al. 1984). While we were not able to find much specific information on the substances used as thermal stabilizers in PVC well casings, in the United States organo-tin compounds have been widely used in PVC potable water pipes (Boettner et al. 1981). Lead compounds are more widely used in other parts of the world such as Great Britain. Specific organo-tin compounds used in the U.S. include methyl-, butyl-, and octyl-tin esters of lauric, maleic, and thioglycolic acids (Boettner et al. 1981). Other stabilizers that have received approval for use in potable water pipes include compounds containing antimony, antimony-tin, calcium-zinc, and zinc (Mc Clelland 1981). While the inorganic components of stabilizers have been found to leach from PVC pipe at measurable levels (Packham 1971a,b,c; Gross et al. 1974; Dietz et al. 1977; Boettner et al. 1981 and McClelland 1981), there is little information regarding leaching of the organic components. Presumably organic species are less soluble and therefore would not leach as readily. Metal leaching is greatest initially (mostly occurring within the first few days) and can be reduced by either precleaning the pipe with detergent, prerinsing it, or by treating it with dilute mineral acid (Packham 1971 a and c). This may also be true with respect to leaching organic constituents. Plasticizers (phthalate esters) are also components of flexible PVC products, but we would not expect to see them leaching from well casings since rigid PVC products do not contain them (plasticizers are added to give flexibility).

In addition to the actual components of well casing materials that may leach substances into ground water, well casings that have been joined by solvent bonds can significantly leach the solvents used to join the pipe (Boettner et al. 1981, Sosebee et al. 1982). Commonly used bonding solvents are tetrahydrofuran, cylclohexanone, methylethylketone, and methylisobutylketone. Because these solvents have been detected leaching into ground water several months after installation of monitoring wells (Sosebee et al. 1982 and Miller 1982), it is generally recommended that only casings and bailers with threaded joints be used for ground water monitoring. These solvents may also dissolve some of the PVC polymer, thereby releasing chloroform and carbon tetrachloride (Desrosiers and Dunnigan 1983).

Miller (1982) looked for leaching of solvent extractable substances, such as plasticizers and other additives, from PVC well casings that had been exposed for 3 to 6 weeks to solutions containing trace levels of several metal and organic substances. The samples were extracted with solvent, concentrated by a factor of 1000, and analyzed using flame ionization gas chromatography (GC-FID). Although Miller did not find any identifiable substances in these leachates, he cautions that leaching may be greater in an actual monitoring situation where ground water is flowing and may contain other more aggressive pollutants.

Curran and Tomson (1983) also tested PVC and Teflon for leaching of contaminants; in their test, water was actually pumped through the tubings. The samples were processed and analyzed using methods very similar to those used by Miller (1982). Curran and Tomson (1983) did not find any analytical interferences in the samples that had been exposed to either Teflon or PVC that had been previously washed with detergent. They concluded that rigid PVC was acceptable for ground water monitoring if the casing is thoroughly washed and rinsed prior to installation.

We also tested several samples of PVC well casing for the leaching of substances that could interfere with analytical determination of these munitions (Parker and Jenkins 1986). We did not find any detectable interferences using reversed-phase HPLC analysis (Jenkins et al. 1986).

Organic substances such as inks or lubricants used during manufacture could possibly leach from stainless steel casings.

In addition to possible analytical problems arising from substances that can be leached from well casing materials, desorption of substances that have been previously sorbed by casing materials could raise the concentration of analytes if the concentrations in the well were to decrease substantially.

Only two studies have addressed desorption of organic constituents (Miller 1982, Jones and Miller 1988). Because the study of Jones and Miller (1988) did not include any control samples, we will not discuss those results. However, Miller (1982) found slight (25%) desorption of tetrachloroethylene from PVC during the first two weeks.

Digest of the literature and proposed study

Generally, we feel that the literature on the interactions of trace level organics with SS, PVC, and PTFE casings is incomplete. Many of the studies we cited only examined one or two of these casing materials; this makes it difficult to compare all four casings. Also, there were problems in the experimental design of a number of these studies; often there was no replication or controls, the data were not quantitative, or effects such as biodegradation could not be ruled out. In addition, many of the authors failed to report the actual data, thereby precluding an independent assessment of the authors' conclusions.

In spite of these problems, some conclusions can be drawn from the literature. First, at least some of the smaller halogenated alkanes and alkenes were slowly sorbed by both PVC and PTFE, and in one instance tetrachloroethylene was rapidly sorbed by PTFE (50% loss within 8 hours). However, based on the data so far, we cannot predict which compounds are most susceptible to loss or the rate of loss. While few studies have examined whether this loss is reversible, there is evidence in at least one study that tetrachloroethylene that has been sorbed by PVC is also slowly desorbed. There does not appear to be any problem with organic substances leaching from PTFE. While there are a number of compounds that possibly could leach from PVC casings and several metal species have been found to leach, there does not appear to be a serious problem with organic substances leaching, especially if the casing is washed with detergent and water prior to use. Also, while one would not expect to find organic substances leaching from stainless steel casings, again the casings should be washed to eliminate any surface contaminants.

The purpose of this study was to compare the performance of these four casing materials when subjected to trace levels of a variety of organic species including several volatile species. This study included control samples and sufficient replication to allow objective statistical analysis of the results. Biocide (mercuric chloride) was added to all the samples to eliminate losses due to biodegradation.

MATERIALS AND METHODS

Five-centimeter (2-in.) -diameter threaded well casings designed specifically for ground water monitoring were used in this study. The casings tested were schedule 40 PVC, Teflon, and 304 and 316 stainless steel. Sections 11 mm in length were cut from the PVC and Teflon casings and those 14 mm in length from the two stainless steel casings. Because the thickness of the walls of the well casings varied, the length was varied so that the final surface area would be the same for all the casings. These ring-shaped sections were then cut into quarters. Special care was taken to eliminate contamination from grease or oil in the cutting process. For each casing material, the pieces were then placed in a large beaker containing deionized water plus detergent and sonicated for 10 minutes. The pieces were then rinsed with deionized water until no suds remained, placed in fresh deionized water, and sonicated for 20 minutes. The water was then poured off, and the pieces were left to air dry on lint-free paper towel. Two pieces of casing were placed in each 40-mL vial. The vials were filled with the aqueous test solution so that there was no headspace and then capped with Teflon-lined plastic caps. Similar vials with no well casing material served as controls. The ratio of the surface area of the casing to solution volume was 0.79 cm^2/mL; this ratio was determined by dividing the surface area inside a 5-cm- diameter pipe by the volume that the pipe would hold, or $SA/V = 2/r$ where r = 2.54 cm. The ratio of solution volume to volume of casing material was approximately 10.

In the first experiment, the test solution was prepared by adding each of the organics directly to 2.2 L of well water (taken from a deep water well in Weathersfield, Vermont) in a stoppered glass bottle. The organics used were RDX, trinitrobenzene (TNB), cis-1,2-dichloroethylene (CDCE), trans-1,2-dichloroethylene (TDCE), m-nitrotoluene (MNT), trichloroethylene (TCE), chlorobenzene (CLB), o-dichlorobenzene (ODCB), p-dichlorobenzene (PDCB), and m-dichlorobenzene (MDCB). The criteria used for selecting these substances included whether they were an EPA priority pollutant, molecular structure, solubility in water, K_{ow} value, and retention time (using reversed-phase HPLC analysis). The final concentration was approximately 2 mg/L for each organic constituent. The solution also contained 40 mg/L $HgCl_2$ to prevent biodegradation of the organics. The bottle was filled to capacity to eliminate any headspace, capped with a ground glass stopper, and then stirred with a magnetic stirrer for 24 hours. The solution was then poured into scintillation vials and capped; separate vials were prepared for each sampling period so that the test solution could be discarded after sampling. For each material and time there were three replicate samples. Sample times were 0 hours, 1 hour, 8 hours, 24 hours (1 day), 72 hours (3 days), 168 hours (1 week) and approximately 1000 hours (6 weeks).

After removing an aliquot for analysis from each of the 1000-hour samples, the vials were emptied, and the pieces of well casing were rinsed with fresh, uncontaminated well water to remove any residual solution adhering to the surfaces. The casing pieces were then placed in clean vials with fresh unspiked well water, capped, and allowed to sit for 3 days. Aliquots taken from these samples were analyzed to determine if desorption had occurred.

In the second experiment 2.0 g of NaCl was also added per liter of solution to test the effect high chloride concentrations had on sorption/desorption. Sampling times were the same except that the last sample was taken after approximately 1200 hours (7 weeks).

All analytical determinations were performed using reversed-phase high performance liquid chromatography (RP-HPLC). A modular system was employed consisting of a Spectra Physics SP 8810 isocratic pump, a Dynatech LC-241 autosampler with a 100-µL loop injector, a Spectra-Physics

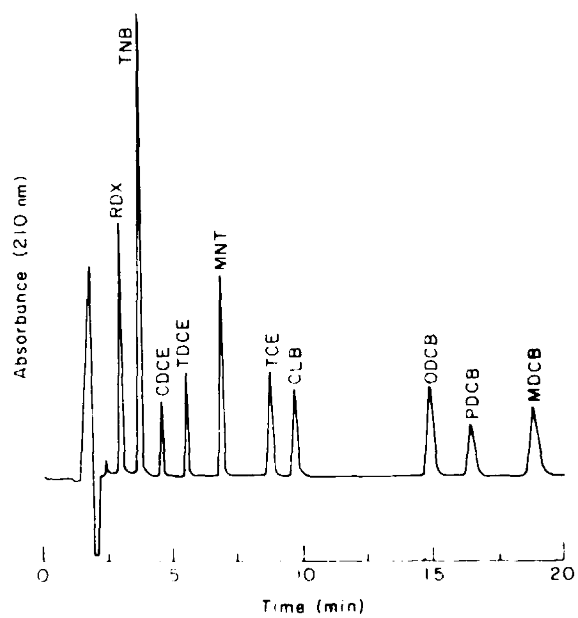

Figure 1. Chromatogram for 10 analytes.

SP8490 variable wavelength UV detector set at 210 nm, a Hewlett-Packard 3393A digital integrator and a Linear model 555 strip chart recorder. Separations were obtained on a 25-cm × 4.6-mm (5 μm) LC-18 column (Supelco) eluted with 1.5 mL/min of 62/38 (V/V) methanol-water. Retention times varied from 3.0 to 18.8 minutes (Table A2). Baseline separation was achieved for all analytes (Fig. 1). Detector response was obtained from the digital integrator operating in the peak height mode. Analytical precision (% RSD) ranged from 0.4 to 3.9% (mean = 1.6%) as determined by the pooled standard deviation of triplicate initial measurements from both studies (Table A2).

Prior to conducting the two experiments described above, a preliminary leaching study was conducted. This study was conducted to determine if any substances leached from the (four) casing materials that could interfere with our analytical method. For this study, two pieces of each type of well casing were placed in each of two vials. The vials were then filled with fresh well water so that there was no headspace, capped and allowed to sit for one week. An aliquot was taken from each vial and analyzed. No detectable peaks were observed in any of the samples.

RESULTS AND DISCUSSION

In the first experiment we compared the four well casing materials with control samples to determine whether there were any losses of the 10 analytes from solution. The complete data from this study are presented in Appendix Tables A3–A12. These data are summarized in Table 1, where the normalized concentrations for the well casings are given with time. For each analyte and time, a one-way analysis of variance test (ANOVA) was performed to determine if the well casing material had any significant effect (at the 95% confidence level). When significant differences were found, a multiple range test was also performed to determine which materials were significantly different from each other. Those values that were significantly different from the control samples were marked with an asterisk in Table 1.

Examining these data reveals that 1) the stainless steel well casings did not affect the concentration of any of the analytes in solution, while PVC and Teflon casings did affect the concentration of some of the analytes, 2) the effect of PVC was considerably less than that of Teflon, and 3) the amount of analyte lost varied with the substance. As an example, Figure 2 shows the concentration of MDCB as a function of time for the four well casing materials. There was no loss of analyte in the samples that contained either stainless steel casing. Loss of MDCB was slow in those samples that contained PVC casing; after 1000 hours the loss was 20%. However, for the samples containing Teflon casing, loss was much more rapid; 20% of the MDCB was lost within the first 24 hours and over 70% was lost after 1000 hours.

There were no statistically significant losses of RDX or TNB in solutions containing any of the well casing materials, even after 1000 hours (Table 1). Loss of MNT was only statistically significant after 1000 hours, when 10% was lost in the samples containing Teflon casings. However, there was significant loss of the remainder of the substances in samples containing Teflon casings and for many of those containing PVC casings.

Loss of CDCE in samples containing Teflon

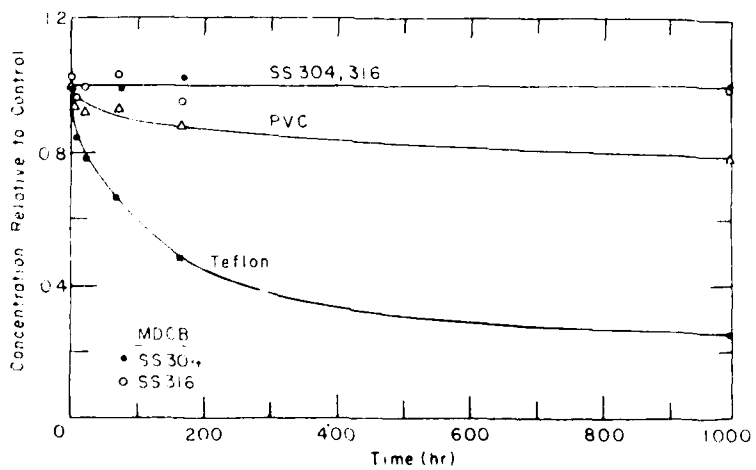

Figure 2. Sorption of MDCB by the four well casing materials.

Table 1. Normalized* concentrations of analytes for the four well casings with time.

Analyte	*Treatment*	*1 hour*	*8 hours*	*24 hours*	*72 hours*	*168 hours*	*1000 hours*
RDX	PTFE	1.03	1.00	1.00	1.02	0.91	0.99
	PVC	1.01	1.00	0.98	1.00	1.02	1.00
	SS304	0.99	0.99	1.01	1.02	1.10	0.98
	SS316	1.01	0.99	1.01	1.02	1.11	1.00
TNB	PTFE	1.01	1.00	1.00	0.98	0.95	1.01
	PVC	1.01	1.00	0.98	1.02	1.01	1.02
	SS304	0.99	1.00	1.00	1.05	1.07	1.00
	SS316	1.02	0.99	1.01	1.07	1.06	1.02
C12DCE	PTFE	1.01	0.96†	0.96†	0.94	0.91†	0.79†
	PVC	1.00	0.99	0.95†	0.96	0.95	0.90
	SS304	0.97	1.00	1.00	0.96	1.04	0.98
	SS316	0.95	0.99	1.00	1.01	0.98	0.99
T12DCE	PTFE	1.00	0.92†	0.88†	0.83	0.66	0.56†
	PVC	1.00	0.98	0.93†	1.06	0.83	0.83
	SS304	0.95†	1.00	1.00	0.96	1.11	1.00
	SS316	1.00	0.99	1.00	1.12	1.03	1.00
MNT	PTFE	1.03	1.00	0.99	0.99	0.90	0.90†
	PVC	1.02	1.00	0.98	1.05	0.99	0.94
	SS304	1.00	1.00	1.01	1.00	1.08	1.07
	SS316	1.02	1.00	1.02	1.08	1.10	0.99
TCE	PTFE	1.00	0.90†	0.85†	0.78†	0.64†	0.40†
	PVC	1.01	0.98	0.94†	0.99	0.94†	0.88†
	SS304	0.96	1.00	1.01	0.96	1.04	0.99
	SS316	1.00	0.99	1.00	1.04	0.98	1.00
CLB	PTFE	1.01	0.93†	0.90†	0.85†	0.74†	0.51†
	PVC	1.01	0.98	0.95†	0.98	0.94†	0.86†
	SS304	0.98	1.00	1.00	0.97	1.05	0.99
	SS316	0.99	0.99	1.01	1.04	0.98	0.99
ODCB	PTFE	1.01	0.91†	0.88†	0.81†	0.68†	0.43†
	PVC	1.02	0.97†	0.94†	0.98	0.93	0.86†
	SS304	0.98	0.99	1.00	0.99	1.04	1.00
	SS316	1.01	0.98†	1.01	1.03	0.98	1.00
PDCB	PTFE	0.92†	0.84†	0.77†	0.64†	0.47†	0.26†
	PVC	0.95	0.95†	0.92†	0.97	0.88†	0.80†
	SS304	0.91†	0.98	1.00	0.98	1.02	1.02
	SS316	0.94	0.97†	1.00	1.04	0.97	1.02
MDCB	PTFE	1.00	0.84†	0.78†	0.66†	0.48†	0.26†
	PVC	1.02	0.95†	0.92†	0.97	0.88†	0.80†
	SS304	0.99	0.96†	1.00	0.99	1.02	1.02
	SS316	1.03	0.96†	1.00	1.04	0.96	1.01

* The values given here are determined by dividing the mean concentration of a given analyte at a given time and for a particular well casing by the mean concentration (for the same analyte) of the control samples taken at the same time.
† Values significantly different from control values.

well casings was relatively slow; losses did not exceed 10% until after 72 hours (Fig. 3). Loss of this compound never exceeded 6% for the samples containing PVC casings.

The trans-isomer of 1,2DCE (TDCE) was lost more rapidly than the cis-isomer from solutions containing Teflon casings (Fig. 3). Generally, loss was significantly greater in the samples with the Teflon casings than in the samples with the PVC casings (Fig. 4). Because significant loss occurred after only 8 hours in samples containing Teflon casings (8% loss), this could impact the water quality of samples taken from wells with longer recharge times (8 to 24 hours). However, this seems less likely for PVC cased wells since loss was only 7% after 24 hours. After 1000 hours, loss was 44% in samples containing Teflon casings and 17% for those containing PVC casings.

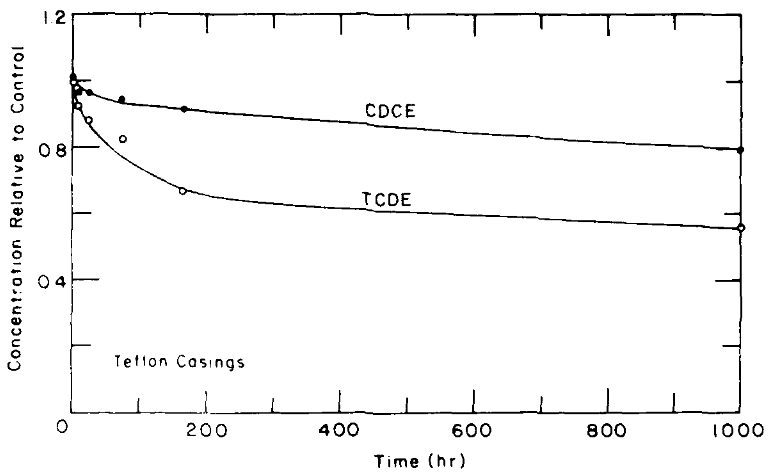

Figure 3. Sorption of CDCE and TDCE by Teflon well casings.

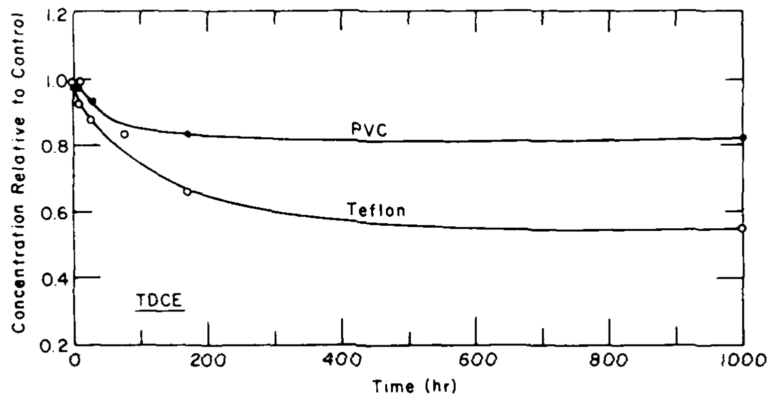

Figure 4. Sorption of TDCE by plastic casings.

The results for TCE were very similar to those of TDCE, except that the final loss was greater in samples containing Teflon casings; loss was 15% after 24 hours and 60% after 1000 hours (Fig. 5). For the samples that contained PVC casings, loss was 5% after 24 hours and only 12% after 1000 hours.

A similar pattern of loss was seen with CLB, ODCB, MDCB, and PDCB. Figure 6 shows the rate of loss of these compounds for samples that contained Teflon casings. The order of loss was MCDB and PDCB > ODCB > CLB. After eight hours, losses were significant in the samples containing Teflon casings; loss was 7% for CLB, 9% for ODCB, and 16% for PDCB and MDCB. For PDCB loss was significant after only 1 hour (8% loss). Although loss of CLB isomers was significant in the samples that contained PVC well casings after only 8 hours, loss was less than 5%. Even after 24 hours losses were less than 10% for CLB and the three DCB compounds.

We also tested the 1000-hour samples to detect if there was any desorption of the sorbed organics from the well casings. After 3 days no analytes were detected in the samples containing either type of stainless steel casing. These results were as expected since no organic had a measurable loss in the samples containing the stainless steel casings. However, for samples containing plastic casings, we did recover measurable quantities of all the organics where significant losses had been observed in the sorption experiment. The results are given in Table 2. While this experiment did not give us any of the kinetics of desorption, generally the amount of analyte desorbed closely paralleled the amount sorbed. No RDX or TNB was recovered from either casing. For those substances that were sorbed, the amount of MNT recovered was the lowest for both casings, and the amount of CDCE recovered was next lowest. However, it is interesting that, for the samples containing Teflon casings, the compounds that were sorbed to the greatest extent (PDCB and MDCB) were not necessarily the substances that were desorbed to the greatest extent (TCE and TDCE were). Diffusion

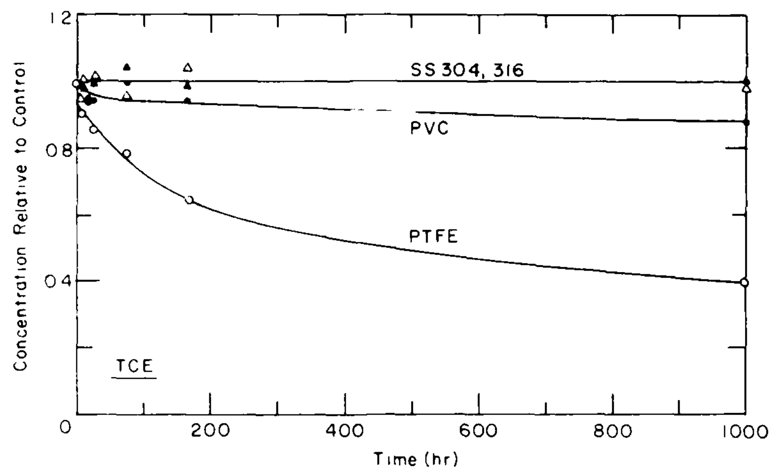

Figure 5. Sorption of TCE by the four well casing materials.

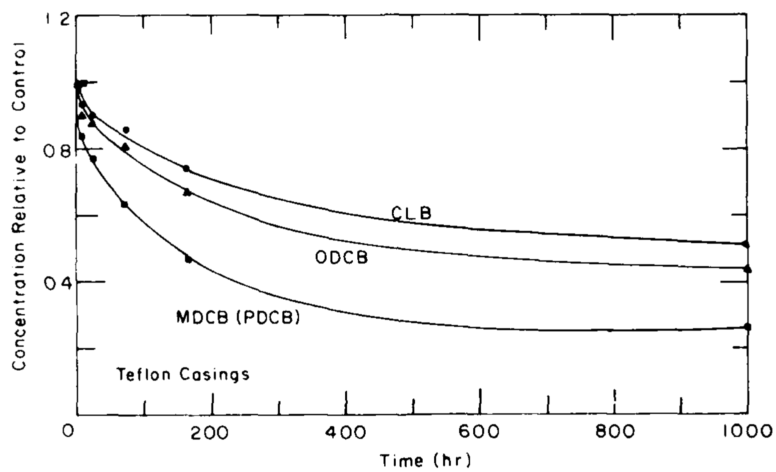

Figure 6. Sorption of CLB, ODCB, MDCB and PDCB by Teflon well casings.

Table 2. Results of desorption study.

Casing material	*Concentration in mg/L after 3 days equilibration*									
	RDX	*TNB*	*CDCE*	*TDCE*	*MNT*	*TCE*	*CLB*	*ODCB*	*PDCB*	*MDCB*
Teflon	ND	ND	0.20	0.43	0.075	0.47	0.28	0.38	0.30	0.35
	ND	ND	0.21	0.45	0.076	0.48	0.28	0.35	0.34	0.36
	ND	ND	0.01*	0.06*	0.074	0.10*	0.06*	0.09*	0.10*	0.12*
PVC	ND	ND	0.079	0.15	0.046	0.14	0.10	0.15	0.17	0.18
	ND	ND	0.080	0.14	0.046	0.12	0.10	0.15	0.16	0.21
	ND	ND	0.080	0.15	0.043	0.13	0.11	0.16	0.16	0.20

* Sample probably had a loose cap.
ND—Not detected.

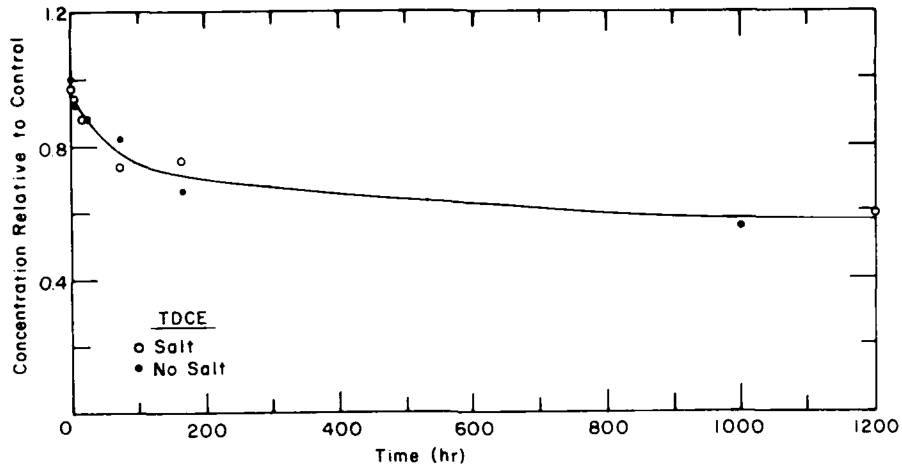

Figure 7. Sorption of TDCE by Teflon well casings in the presence and absence of salt.

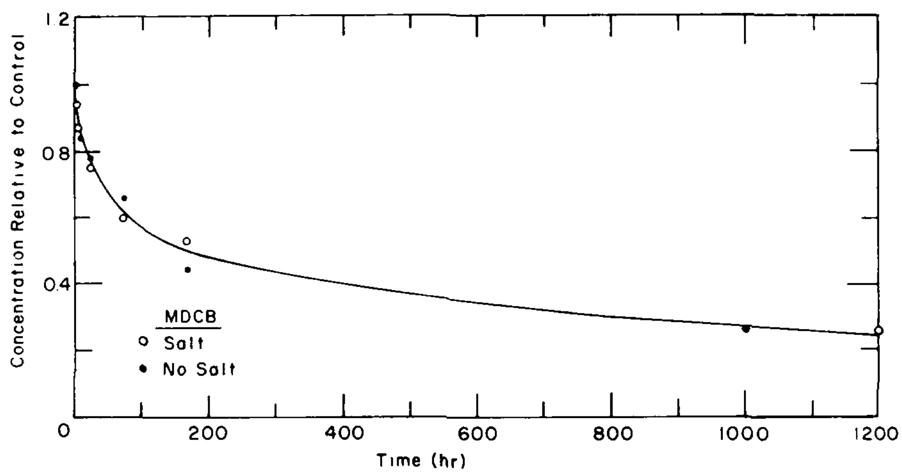

Figure 8. Sorption of MDCB by Teflon well casings in the presence and absence of salt.

out of the polymer may be more rapid for the smaller, more planar molecules.

Experiment with NaCl-amended ground water

In the second experiment we added NaCl to raise the chloride concentration above 1000 mg/L. High chloride concentrations are known to be corrosive to 304 stainless steel. Specifically, we wondered if over the long term, rusting would have any effect on the performance of the stainless casings. It is also possible that sorption on plastic materials would increase with increasing ionic strength.

Rusting of the stainless casings was visible after only 8 hours for SS 304 and, after 24 hours for SS 316. However, the addition of sodium chloride did not seem to affect the rate of loss of any of the analytes studied for either the stainless steel or plastic casings. Tables A13–A22 give the data for the 10 analytes. The data were analyzed using standard analysis of variance to determine any significant effects, and multiple range tests were performed to determine which materials were significantly different from each other. Table A23 summarizes the data by giving the normalized values for the well casings; values that were significantly different from the control values are marked with an asterisk.

Figures 7 and 8 are plots of the concentrations of TDCE and MDCB, respectively, as a function of time for sample solutions, with and without added chloride, containing Teflon casings. Clearly the addition of salt did not markedly affect the rate or amount of sorption of these analytes. This was also found to be true when similar plots were drawn for the TCE, CLB, and ODCB.

Table 3. Several physical constants of the analytes.

Analyte	Molecular weight[1]	Solubility (mg/L)	Log K_{ow}
RDX	222.15	43[4]	0.87[2] 0.88[6]
TNB	213.11	—	1.18[6]
CDCE	96.95	3500[5]	1.63[7]
TDCE	96.95	6300[5]	1.93[7]
MNT	137.13	498[1]	2.45[3]
TCE	131.40	1100[5]	2.29[2] 2.42[2]
CLB	112.56	488[1]	2.18[3] 2.46[3] 2.84[3]
ODCB	147.01	145[1]	3.38[3] 3.40[2]
PDCB	147.01	79[1]	3.38[3] 3.39[3] 3.37[2]
MDCB	147.01	123[1]	3.38[3] 3.44[2]

1. Hodgman (1955).
2. Banerjee et al. (1980).
3. Hansch and Leo (1979).
4. Leggett (CRREL, pers. comm, 1986).
5. MacKay and Shiu (1981).
6. Jenkins (1989).
7. Estimated for HPLC capacity factor (McDuffie 1981).

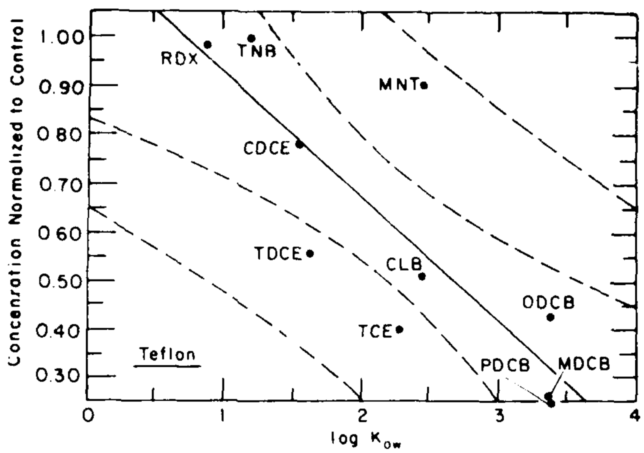

Figure 9. Regression analysis for concentration vs log K_{ow} for samples containing Teflon casings.

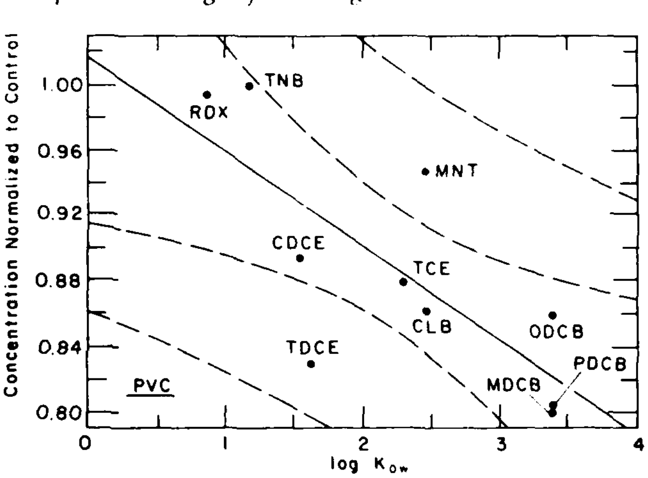

Figure 10. Regression analysis for concentration vs log K_{ow} for samples containing PVC casings.

Relationship of sorption to analyte properties

We performed regression analyses on the concentration of analyte in the 1000- hour samples containing either the PVC or Teflon casings vs the corresponding aqueous solubilities, molecular weights, or log octanol/water partition coefficients (K_{ow}) of the analytes (see Table 3 for constants). We found a statistically significant (95% confidence level) inverse relationship between the concentration of analyte relative to the control samples and the log K_{ow} values for both the PVC and Teflon casings. Tables A24 and A25 summarize the regression analyses for the Teflon and PVC data, respectively, and Figures 9 and 10 show the corresponding plots of (normalized) concentration of each analyte vs its log K_{ow}. The relationship with K_{ow} was the most highly significant and the only one that was significant when a stepwise multiple regression was performed to test for the addition of the other variables (using "Statgraphics" software by STSC Inc., Rockville, Md.).

Modeling the sorption process

While these experiments clearly demonstrated that the loss of organic chemicals from solutions exposed to plastic casing materials is a sorption process, it is not clear whether this is a surface phenomenon or whether penetration into the polymer matrix occurred. During the desorption studies the sorbed analytes were released back into solution, thereby demonstrating that the process is at least partially reversible. While surface adsorption cannot be ruled out, the evidence suggests that diffusion into the polymer matrix occurred. Zhang et al. (1988) showed that organic molecules penetrate plasticized PVC membranes. In our experiments sorption appears to be slow (taking hundreds of hours to attain equilibrium), which suggests that partitioning into the bulk of the material occurs. Desorption of some analytes from Teflon also appeared to be slow. If we assume this to be the case, the process can be modeled using classical partitioning by treating the plastic casing as an immiscible liquid phase in contact with water and relating partitioning of individual analytes to their K_{ow} values. While immiscible liquids other than octanol may be better structural models of Teflon or PVC, the most extensive collection of partition coefficients is available for octanol. This is because K_{ow} values have been used successfully to predict the behavior of drugs in the human body and the sorption of environmental pollutants on sediments and soils.

Because it appears that we can predict the behavior of the various analytes exposed to plastic casings on the basis of their K_{ow} values, we modeled the partitioning process as follows. First, if we assume that the sorption process is a simple, reversible first order process (eq 2), we can write the rate equation as shown in eq 3 (Gould 1959):

$$X_{aq} = \frac{k_1}{k_2} X_{sorb} \tag{2}$$

$$\frac{d[X_{aq}]}{dt} = -k_1[X_{aq}] + k_2[X_{sorb}] \tag{3}$$

where $[X_{aq}]$ = the concentration of the analyte X in aqueous solution
$[X_{sorb}]$ = the concentration of analyte X sorbed in the plastic material
k_1 = the rate constant for sorption
k_2 = the rate constant for desorption
t = time in hours.

Since in our experiments the volume of the solution was 10 times the volume of the plastic casing, or

$$V_{aq} = 10 \cdot V_{sorb} \tag{4}$$

then

$$[X_{aq}] = [X_0] - \left[\frac{X_{sorb}}{10}\right] \tag{5}$$

where $[X_0]$ is the initial concentration of X in solution. Solving for $[X_{sorb}]$ we have

$$[X_{sorb}] = 10([X_0] - [X_{aq}]). \tag{6}$$

Substituting back into eq 2 we have

$$\frac{d[X_{aq}]}{dt} = -k_1[X_{aq}] + k_2(10[X_0] - [X_{aq}]). \tag{7}$$

Regrouping terms we have

$$\frac{d[X_{aq}]}{dt} = -(k_1+k_2)\,[X_{aq}] + 10k_2[X_0]. \tag{8}$$

Since k_1, k_2 and $[X_0]$ are constants, we can rewrite this as

$$\frac{d[X_{aq}]}{dt} = -A[X_{aq}] + B \tag{9}$$

where

$$A = k_1 + k_2 \tag{10}$$

and

$$B = 10k_2[X_0]. \tag{11}$$

If we then integrate the rate equation we have a nonlinear relation for $[X_{aq}]$ as a function of t and two constants, A and B:

$$\frac{\ln[A[X_{aq}] + B]}{A} = t\,. \tag{12}$$

We obtained the optimal values for A and B for each analyte, where sorption loss was observed, by application of the Gauss-Newton method of nonlinear curve fitting using the measured aqueous concentrations at 1, 8, 24, 72, 128 and 1000 hours. Then using these values for A and B, we simultaneously solved eq 10 and 11 for each analyte to obtain values for k_1 and k_2 (the rate constants for the forward and reverse processes). The values for Teflon are shown in Table 4. Since the process we describe is assumed to be reversible and of first order, the ratio of the rate constants, k_1/k_2, is the equilibrium constant, K_{eq}. The K_{eq} and the log K_{ow} values for each analyte are also given in Table 4.

When we plotted the eight values of K_{eq} given in Table 4 vs log K_{ow}, six of the eight points appeared to fall on a straight line, while the points for MNT and ODCB did not (Fig. 11). The poor fit for MNT and the lack of significant sorption for TNB and RDX can be explained by the tendency of nitro-containing organic molecules to form strong hydrogen bonds, which keeps them in solution. While octanol can be a donor in hydrogen bonding, Teflon cannot. Thus, if we predict partitioning into Teflon for these molecules based on their octanol/water coefficients, we will overestimate the amount of sorption. For example, based on our

Table 4. Sorption (k_1) and desorption (k_2) rate constants and equilibrium constant (K_{eq}) for exposure to Teflon.

Analyte	$k_1 \times 10^2$ (cm^{-1})	$k_2 \times 10^4$ (cm^{-1})	K_{eq}	*Log* K_{ow}
RDX	*	*	*	0.88[2]
TNB	*	*	*	1.18[1]
MNT	0.699	3.100	22.3	2.40[1]
C12DCE	1.590	6.253	25.4	1.63[3]
T12DCE	1.935	6.116	31.6	1.93[1]
ODCB	1.100	3.064	35.9	3.38[1]
CLB	0.827	2.300	36.0	2.46[1]
TCE	1.543	4.067	37.9	2.29[1]
MDCB	1.408	2.779	50.7	3.38[1]
PDCB	1.558	3.005	51.9	3.39[1]

1. Hansch and Leo (1979).
2. Jenkins (1989).
3. Estimated for RP-HPLC capacity factor using method of McDuffie (1981).
* Loss not statistically significant so no estimate possible.

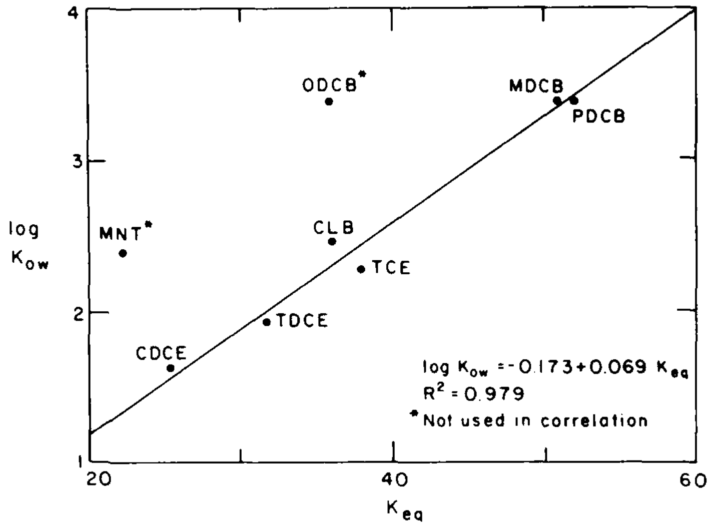

Figure 11. Correlation between log octanol–water partition coefficient (K_{ow}) and equilibrium constant (K_{eq}) for solutes exposed to Teflon well casing.

regression equation we predict a K_{eq} of 38 for MNT; however, the observed K_{eq} was only 22.3.

The poor prediction for ODCB can be explained by the well known "ortho effect." This effect is a complex combination of electronic and steric influences, which often results in ortho-di-substituted aromatic molecules behaving much differently than the meta- and para-isomers.

We did not create a similar model predicting the loss of analyte for PVC because the percent sorbed was small when compared with the experimental error and this would create an unacceptable degree of uncertainty in the calculated rate constants.

Therefore, we conclude that, for hydrophobic organic molecules that are not subject to hydrogen bonding, the relationship presented in Figure 11 can be used to estimate the equilibrium partitioning of an analyte between the aqueous phase and Teflon. Obviously, in a well, the ground water is refreshed and one would not observe the levels of depletion we observed in our study. However, eventually the plastic casing should reach equilibrium with the aqueous phase if the concentration of the analyte in ground water is relatively constant with time.

While K_{eq} will determine the equilibrium concentrations of each analyte in the water and plastic phases, it is the magnitude of k_1 that will determine how quickly various analytes are depleted. For small, planar molecules like TCE, the k_1 values are quite high compared to those of the other analytes. This may explain the rapid loss of tetrachloroethylene from solutions containing Teflon casings observed by Miller (1982) and Reynolds and Gillham (1986).

CONCLUSIONS AND RECOMMENDATIONS

These studies indicate that Teflon was clearly the poorest choice of the four well casing materials tested when samples are to be analyzed for trace level organics. Significant losses of all the chlorinated compounds occurred within 1–8 hours, and one nitroaromatic compound was also lost after prolonged exposure (1000 hours). While losses were also seen for several compounds exposed to PVC, the rate of loss was always much slower than for the Teflon casings; usually 24 hours lapsed before significant losses occurred. There was no loss of any organic tested in the presence of either SS casing. However, rusting of both types of stainless casings occurred relatively quickly, in some instances overnight.

The desorption study showed that loss of organics from aqueous solution is due to a sorption process, and that the sorption process is partially reversible. Desorption from well casing material could result in falsely high concentrations of analytes if their concentrations were to decrease in the well water.

We were able to correlate the loss of hydrophobic organic constituents in the well water containing Teflon casings with the substance's K_{ow} values. However, for hydrophilic organic substances this correlation overestimates losses.

Our results indicate that in a monitoring situation, where the well is purged and then sampled within 8–24 hours, PVC cased wells are probably suited for sampling most organics while Teflon cased wells are probably not. However, there are two conflicting effects that must be considered when extrapolating our test data to a real monitoring situation: 1) we tested casings, not well screens; the greater surface area of well screens could substantially increase the rate of sorptive losses in the screened portion of the well, and 2) this experiment was conducted under static conditions. If there is a long time between purging the well and sampling, it is possible that the water being sampled would be at least partially replenished, and this would tend to mitigate losses due to sorption by the casing material.

The larger question is what is the best casing for ground water monitoring? Our study attempts to answer only part of the question—how suitable are these four well casing materials for monitoring organic constituents? Inorganic constituents must also be considered and for that we refer the reader to Hewitt (1989). Hewitt's results for inorganics show nearly opposite behavior. He found that Teflon casings were the best for monitoring four species of metals (Cd, Cr, As and Pb) while stainless steel casings were the worst; rusting by the stainless steel casings presented serious problems with several of the analytes. Clearly, selecting a single casing material, from those tested, for monitoring both inorganic and organic constituents in ground water will necessarily have to involve compromise.

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APPENDIX A: TEST DATA

Table A1. Time at which absorption reduced the relative concentration (C/C_0) in solution to 0.9.[1]

Polymer	Least Absorption ---------------------→				Most Absorption
PVC	TRI > 5 weeks	TET ~ 2 weeks	BRO ~ 3 days	HEX ~ 1 day	TEY ~ 1 day
PTFE	BRO > 5 weeks	TET ~ 2 weeks	TRI ~ 1 day	HEX ~ 1 day	TEY < 5 min.
Log (undecane/water partition coefficient)	TET 2.04	BRO 2.10	TRI 2.62	HEX Not Reported	TEY 3.43
Water Solubility (mg/L)	BRO 3100	TET 2962	TRI 1495	TEY 150	HEX 50
Log (Octanol/Water partition coefficient)	BRO 2.30	TRI 2.49	TET 2.56	TEY 2.60	HEX 3.34

TRI = 1,1,1-trichloroethane
TET = 1,1,2,2-tetrachloroethane
BRO = bromoform
HEX = hexachloroethane
TEX = tetrachloroethylene

[1] Reynolds and Gillham, 1986.

Table A2. Retention times and analytical precision.

Substance	Abbreviation	Precision RSD (%)
1,3,5-trinitro-1,3,5-triazine	RDX	1.0
1,3,5-trinitrobenzene	TNB	0.9
cis-1,2-dichloroethylene	CDCE	3.9
trans-1,2-dichloroethylene	TDCE	1.9
m-nitrotoluene	MNT	0.4
trichloroethylene	TCE	2.2
chlorobenzene	CLB	1.6
o-dichlorobenzene	ODCB	1.4
p-dichlorobenzene	PDCB	1.6
m-dichlorobenzene	MDCB	1.5

Table A3. Concentration of RDX with time.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	1.79	1.74	1.72	1.82	1.75	2.19	1.63
SS304	1.79	1.75	1.70	1.77	1.76	2.20	1.70
SS304	1.78	1.69	1.71	1.72	1.76	1.90	1.69
SS316	1.79	1.76	1.70	1.77	1.75	2.20	1.71
SS316	1.79	1.76	1.71	1.77	1.76	2.19	1.72
SS316	1.78	1.78	1.70	1.75	1.75	1.97	1.70
PVC	1.79	1.76	1.70	1.74	1.73	2.19	1.70
PVC	1.79	1.78	1.72	1.71	1.76	1.74	1.70
PVC	1.78	1.73	1.72	1.70	1.69		1.71
TEFLON	1.79	1.77	1.72	1.77	1.73	1.73	1.67
TEFLON	1.79	1.90	1.72	1.76	1.77	1.73	1.69
TEFLON	1.78	1.73	1.72	1.70	1.74	1.73	1.71
CONTROL	1.79	1.74	1.74	1.76	1.77	2.14	1.67
CONTROL	1.79	1.75	1.70	1.74	1.70	1.68	1.68
CONTROL	1.78	1.74	1.72	1.74	1.69		1.77

Table A4. Concentration of TNB with time.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	2.37	2.29	2.28	2.33	2.26	2.52	2.19
SS304	2.37	2.28	2.26	2.35	2.33	2.53	2.30
SS304	2.36	2.25	2.27	2.28	2.34	2.26	2.32
SS316	2.37	2.35	2.25	2.34	2.45	2.50	2.33
SS316	2.37	2.32	2.27	2.32	2.28	2.45	2.31
SS316	2.36	2.31	2.26	2.34	2.35	2.31	2.30
PVC	2.37	2.32	2.25	2.25	2.09	2.53	2.24
PVC	2.37	2.36	2.28	2.25	2.20	2.18	2.34
PVC	2.36	2.28	2.28	2.29	2.45	2.19	2.34
TEFLON	2.37	2.34	2.28	2.33	2.29	2.24	2.28
TEFLON	2.37	2.36	2.28	2.35	2.12	2.06	2.29
TEFLON	2.36	2.27	2.27	2.24	2.09	2.18	2.32
CONTROL	2.37	2.29	2.29	2.29	2.16	2.48	2.23
CONTROL	2.37	2.30	2.26	2.33	2.17	2.27	2.28
CONTROL	2.36	2.29	2.28	2.31	2.27	2.08	2.30

Table A5. Concentration of MNT with time.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	2.32	2.20	2.23	2.30	2.20	2.63	
SS304	2.32	2.23	2.23	2.33	2.23	2.70	2.02
SS304	2.30	2.25	2.23	2.25	2.23	2.29	
SS316	2.32	2.33	2.23	2.33	2.57	2.75	2.00
SS316	2.32	2.23	2.22	2.32	2.25	2.61	2.02
SS316	2.30	2.24	2.23	2.32	2.24	2.41	2.08
PVC	2.32	2.30	2.21	2.21	2.21	2.60	2.02
PVC	2.32	2.32	2.22	2.21	2.25	2.24	1.87
PVC	2.30	2.20	2.23	2.25	2.53	2.15	1.95
TEFLON	2.32	2.31	2.22	2.28	2.17	2.13	
TEFLON	2.32	2.32	2.22	2.30	2.20	2.11	1.87
TEFLON	2.30	2.20	2.22	2.19	2.17	2.09	1.84
CONTROL	2.32	2.21	2.22	2.26	2.22	2.65	2.11
CONTROL	2.32	2.23	2.22	2.30	2.28	2.28	
CONTROL	2.30	2.22	2.24	2.28	2.13	2.12	2.01

Table A6. Concentration of CDCE with time.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	2.79	2.55	2.78	2.57	2.51	2.37	2.21
SS304	2.84	2.66	2.76	2.63	2.35	2.42	
SS304	2.73	2.60	2.75	2.62	2.10	2.41	
SS316	2.79	2.59	2.76	2.64	2.52	2.37	2.09
SS316	2.84	2.68	2.72	2.59	2.46	2.16	2.30
SS316	2.73	2.39	2.73	2.56	2.37		2.26
PVC	2.79	2.71	2.75	2.44	2.33	2.24	1.94
PVC	2.84	2.73	2.76	2.47	2.31	2.24	1.95
PVC	2.73	2.61	2.68	2.48	2.34	2.12	2.15
TEFLON	2.79	2.74	2.68	2.48	2.28	2.19	1.77
TEFLON	2.84	2.74	2.64	2.45	2.33	2.10	1.76
TEFLON	2.73	2.64	2.66	2.52	2.21	2.02	
CONTROL	2.79	2.66	2.79	2.57	2.43	2.38	2.13
CONTROL	2.84	2.71	2.79	2.63	2.56	2.38	2.36
CONTROL	2.73	2.68	2.72	2.60	2.26	2.19	

Table A7. Concentration of TDCE with time.

treatment	Concentration mg/L						
	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	2.71	2.43	2.70	2.43	2.29	2.86	
SS304	2.77	2.53	2.68	2.44	2.22	2.93	2.03
SS304	2.63	2.38	2.67	2.39	1.87	2.21	
SS316	2.71	2.66	2.66	2.46	2.87		1.89
SS316	2.77	2.47	2.65	2.41	2.37	2.84	2.13
SS316	2.63	2.58	2.69	2.35	2.21	2.07	2.11
PVC	2.71	2.62	2.58	2.22	2.11	1.99	1.82
PVC	2.77	2.61	2.66	2.25	2.11	1.99	1.64
PVC	2.63	2.48	2.64	2.26	2.83	1.97	1.63
TEFLON	2.71	2.62	2.48	2.08	1.82	1.64	
TEFLON	2.77	2.62	2.45	2.16	1.88	1.49	1.13
TEFLON	2.63	2.50	2.46	2.13	1.83	1.58	1.14
CONTROL	2.71	2.55	2.70	2.38	2.22	2.88	2.14
CONTROL	2.77	2.61	2.72	2.44	2.34	2.15	
CONTROL	2.63	2.58	2.63	2.41	2.12	2.14	1.95

Table A8. Concentration of TCE with time.

treatment	Concentration mg/L						
	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	2.80	2.48	2.77	2.55	2.38	2.29	
SS304	2.85	2.59	2.75	2.60	2.29	2.36	2.21
SS304	2.71	2.52	2.74	2.52	1.96	2.40	
SS316	2.80	2.76	2.74	2.61	2.40	2.31	2.08
SS316	2.85	2.53	2.72	2.56	2.47		2.30
SS316	2.71	2.64	2.76	2.48	2.34	2.15	2.29
PVC	2.80	2.70	2.67	2.37	2.31	2.17	2.07
PVC	2.85	2.72	2.74	2.40	2.33	2.15	1.92
PVC	2.71	2.55	2.72	2.42	2.25	2.11	1.89
TEFLON	2.80	2.69	2.50	2.13	1.72	1.53	
TEFLON	2.85	2.68	2.47	2.20	1.86	1.41	0.89
TEFLON	2.71	2.53	2.48	2.15	1.80	1.43	0.90
CONTROL	2.80	2.61	2.78	2.51	2.31	2.32	2.31
CONTROL	2.85	2.67	2.80	2.57	2.46	2.31	
CONTROL	2.71	2.64	2.70	2.55	2.16	2.18	2.14

Table A9. Concentration of CLB with time.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	2.18	1.95	2.13	2.04	1.95	1.90	
SS304	2.12	2.03	2.13	2.08	1.91	1.97	1.56
SS304	2.13	2.05	2.14	2.12	1.73	1.98	
SS316	2.18	1.98	2.14	2.05	1.98	1.91	1.47
SS316	2.12	2.05	2.12	2.09	2.03		1.59
SS316	2.13	2.06	2.11	2.12	1.97	1.80	1.62
PVC	2.18	2.12	2.08	1.93	1.88	1.78	1.32
PVC	2.12	2.12	2.11	1.95	1.91	1.78	1.32
PVC	2.13	2.00	2.13	1.97	1.84	1.74	1.45
TEFLON	2.18	2.12	1.98	1.84	1.57	1.45	
TEFLON	2.12	2.12	1.99	1.85	1.69	1.35	0.81
TEFLON	2.13	1.99	2.00	1.90	1.64	1.37	0.81
CONTROL	2.18	2.05	2.11	2.05	1.92	1.93	
CONTROL	2.12	2.04	2.15	2.07	2.03	1.92	1.51
CONTROL	2.13	2.08	2.16	2.10	1.80	1.82	1.64

Table A10. Concentration of ODCB with time.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	2.31	2.12	2.28	2.22	2.16		
SS304	2.36	2.20	2.29	2.28	2.12	2.16	1.97
SS304	2.40	2.21	2.29	2.32	1.99	2.17	
SS316	2.31	2.14	2.26	2.25	2.16	2.13	1.87
SS316	2.36	2.21	2.26	2.30	2.22		1.97
SS316	2.40	2.35	2.29	2.31	2.16	1.94	2.04
PVC	2.31	2.15	2.22	2.09	2.06	1.95	1.64
PVC	2.36	2.31	2.24	2.11	2.09	1.97	1.65
PVC	2.40	2.31	2.27	2.16	2.03	1.87	1.78
TEFLON	2.31	2.12	2.10	1.94	1.65	1.48	
TEFLON	2.36	2.29	2.10	1.99	1.76	1.31	0.85
TEFLON	2.40	2.30	2.11	2.03	1.72	1.39	0.85
CONTROL	2.31	2.20	2.28	2.25	2.15	2.16	2.02
CONTROL	2.36	2.20	2.31	2.26	2.23	2.13	
CONTROL	2.40	2.24	2.33	2.29	1.95	1.96	1.92

Table A11. Concentration of MDCB with time.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	2.27	1.99	2.14	2.21	2.09	1.94	
SS304	2.29	2.01	2.12	2.25	2.03	2.06	1.82
SS304	2.23	2.15	2.20	2.16	1.86	2.06	
SS316	2.27	2.11	2.10	2.15	2.09	2.01	1.70
SS316	2.29	2.05	2.14	2.24	2.15		1.81
SS316	2.23	2.28	2.20	2.25	2.06	1.82	1.89
PVC	2.27	2.23	2.14	2.06	1.95	1.76	1.39
PVC	2.29	1.96	2.18	2.02	1.96	1.80	1.39
PVC	2.23	2.21	2.09	2.00	1.96	1.71	1.51
TEFLON	2.27	2.21	1.86	1.75	1.26	1.02	0.47
TEFLON	2.29	2.13	1.87	1.67	1.38	0.89	0.48
TEFLON	2.23	1.92	1.89	1.72	1.35	0.96	
CONTROL	2.27	2.06	2.19	2.19	2.06	2.06	
CONTROL	2.29	2.06	2.22	2.20	2.15	2.04	1.83
CONTROL	2.23	2.11	2.31	2.23	1.84	1.86	

Table A12. Concentration of PDCB with time.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1000hr
SS304	1.97	1.79	1.94	1.87	1.79	1.68	
SS304	2.02	1.86	1.94	1.90	1.74	1.78	1.55
SS304	2.05	1.85	1.94	1.95	1.60	1.78	
SS316	1.97	2.00	1.92	1.86	1.80	1.75	1.50
SS316	2.02	1.81	1.92	1.93	1.84		1.56
SS316	2.05	1.88	1.93	1.94	1.81	1.58	1.60
PVC	1.97	1.81	1.87	1.73	1.66	1.52	1.21
PVC	2.02	1.97	1.88	1.74	1.68	1.55	1.22
PVC	2.05	1.97	1.90	1.77	1.72	1.47	1.24
TEFLON	1.97	1.76	1.64	1.42	1.06	0.85	0.40
TEFLON	2.02	1.90	1.65	1.47	1.16	0.74	0.38
TEFLON	2.05	1.91	1.67	1.49	1.15	0.82	
CONTROL	1.97	2.02	1.93	1.89	1.77	1.78	1.49
CONTROL	2.02	2.05	1.97	1.90	1.84	1.74	1.55
CONTROL	2.05	1.97	2.03	1.93	1.63	1.61	

Table A[illegible]. Concentration of RDX with time--salt study.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1200hr
SS304	1.87	2.06	2.03	2.09	2.02	2.18	2.01
SS304	1.92	2.05	2.04	2.10	2.00	2.18	2.02
SS304	1.99	2.08	2.05	2.07	1.98	2.17	1.97
SS316	1.87	2.78	2.01	2.59	1.96	2.17	2.06
SS316	[illegible]	2.07	2.07	2.12	2.01	2.18	2.04
SS316	[illegible]	[illegible]	2.04	[illegible]	2.01	2.19	[illegible]
PVC	1.87	2.07	2.04	2.07	1.91	2.18	1.98
PVC	1.91	2.07	2.05	2.12	2.06	2.18	2.02
PVC	[illegible]	[illegible]	[illegible]	2.07	[illegible]	2.18	[illegible]
TEFLON	[illegible]	[illegible]	[illegible]	2.06	1.98	2.18	[illegible]
TEFLON	[illegible]	[illegible]	[illegible]	[illegible]	2.07	2.19	[illegible]
TEFLON	[illegible]	[illegible]	[illegible]	2.60	[illegible]	[illegible]	[illegible]
CONTROL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CONTROL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

Table A15. Concentration of MNT with time--salt study.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1200hr
SS304	2.16	2.20	2.10	2.12	2.19	2.12	2.28
SS304	2.19	2.16	2.11	2.13	2.17	2.13	2.13
SS304	2.16	2.16	2.09	2.10	2.12	2.10	2.14
SS316	2.16	2.16	2.11	2.21	2.19	2.12	2.17
SS316	2.19	2.16	2.11	2.16	2.18	2.10	2.15
SS316	2.16	2.14	2.09	2.17	2.11	2.09	2.09
PVC	2.16	2.17	2.13	2.13	2.16	2.10	2.07
PVC	2.19	2.17	2.13	2.14	2.14	2.08	2.05
PVC	2.16	2.15	2.11	2.08	2.10	2.06	2.06
TEFLON	2.16	2.10	2.05	2.16	2.16	2.05	2.06
TEFLON	2.19	2.16	2.08	2.15	2.12	2.04	2.03
TEFLON	2.16	2.16	2.09	2.06	2.08	2.05	1.85
CONTROL	2.16	2.15	2.12	2.21	2.17	2.12	2.29
CONTROL	2.19	2.15	2.10	2.15	2.21	2.09	2.20
CONTROL	2.16	2.16	2.10	2.12	2.22	2.11	2.21

Table A16. Concentration of CDCE with time--salt study.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1200hr
SS304	2.58	2.58	2.46	2.45	2.40	2.28	2.22
SS304	2.58	2.54	2.47	2.47	2.46	2.35	1.86
SS304	2.61	2.58	2.38	2.49	2.16	2.21	2.05
SS316	2.58	2.51	2.42	2.51	2.36	2.29	1.85
SS316	2.58	2.47	2.50	2.54	2.36	2.23	2.21
SS316	2.61	2.51	2.42	2.46	2.41	2.24	2.05
PVC	2.58	2.58	2.46	2.39	2.36	2.19	1.59
PVC	2.58	2.57	2.51	2.41	2.31	2.24	1.73
PVC	2.61	2.52	2.43	2.40	2.31	2.18	1.88
TEFLON	2.58	2.45	2.40	2.43	1.86	2.01	1.53
TEFLON	2.58	2.50	2.42	2.45	2.24	2.09	1.65
TEFLON	2.61	2.57	2.37	2.36	2.25	2.14	1.74
CONTROL	2.58	2.57	2.44	2.54	2.39	2.25	2.17
CONTROL	2.58	2.52	2.41	2.53	2.46	2.24	1.88
CONTROL	2.61	2.53	2.50	2.49	2.41	2.32	1.88

Table A17. Concentration of TDCE with time--salt study.

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1200hr
	Concentration mg/L						
SS304	1.93	1.91	1.82	1.79	1.70	1.58	1.39
SS304	1.91	1.88	1.81	1.81	1.75	1.65	1.01
SS304	1.95	1.91	1.74	1.84	1.47	1.52	1.21
SS316	1.93	1.85	1.78	1.84	1.71	1.59	1.00
SS316	1.91	1.83	1.85	1.87	1.67	1.54	1.40
SS316	1.95	1.85	1.77	1.79	1.67	1.55	1.27
PVC	1.93	1.92	1.80	1.73	1.65	1.46	0.76
PVC	1.91	1.90	1.85	1.74	1.59	1.50	0.87
PVC	1.95	1.86	1.77	1.74	1.58	1.45	1.03
TEFLON	1.93	1.78	1.70	1.65	1.39	1.12	0.66
TEFLON	1.91	1.82	1.71	1.67	1.36	1.19	0.63
TEFLON	1.95	1.88	1.66	1.60	1.07	1.23	0.76
CONTROL	1.93	1.91	1.80	1.87	1.69	1.55	1.37
CONTROL	1.91	1.87	1.77	1.86	1.75	1.56	1.03
CONTROL	1.95	1.87	1.85	1.83	1.70	1.61	1.00

Table A18. Concentration of TCE with time--salt study.

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1200hr
	Concentration mg/L						
SS304	2.82	2.80	2.66	2.60	2.51	2.34	2.10
SS304	2.79	2.75	2.64	2.61	2.58	2.43	1.48
SS304	2.86	2.80	2.54	2.65	2.17	2.24	1.82
SS316	2.82	2.73	2.61	2.69	2.55	2.34	1.46
SS316	2.79	2.70	2.70	2.72	2.46	2.27	2.03
SS316	2.86	2.71	2.59	2.61	2.44	2.27	1.86
PVC	2.82	2.81	2.71	2.55	2.49	2.21	1.21
PVC	2.79	2.80	2.60	2.55	2.39	2.27	1.36
PVC	2.86	2.72	2.65	2.54	2.32	2.19	1.63
TEFLON	2.82	2.59	2.44	2.30	1.90	1.47	0.80
TEFLON	2.79	2.64	2.44	2.33	1.84	1.55	0.68
TEFLON	2.86	2.73	2.38	2.24	1.50	1.62	0.66
CONTROL	2.82	2.79	2.63	2.72	2.49	2.29	2.04
CONTROL	2.79	2.74	2.59	2.70	2.60	2.30	1.54
CONTROL	2.86	2.74	2.70	2.65	2.51	2.38	1.50

Table A19. Concentration of CLB with time--salt study.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1200hr
SS304	1.78	1.75	1.63	1.66	1.49	1.55	1.31
SS304	1.78	1.77	1.68	1.67	1.67	1.49	1.40
SS304	1.81	1.78	1.69	1.68	1.69	1.60	1.59
SS316	1.78	1.72	1.63	1.44	1.62	1.50	1.31
SS316	1.78	1.73	1.67	1.73	1.64	1.51	1.41
SS316	1.31	1.73	1.70	1.74	1.67	1.55	1.51
PVC	1.78	1.74	1.65	1.41	1.54	1.45	1.10
PVC	1.78	1.77	1.69	1.64	1.58	1.47	1.17
PVC	1.81	1.78	1.71	1.61	1.62	1.49	1.24
TEFLON	1.78	1.67	1.56	1.50	1.19	1.14	0.65
TEFLON	1.78	1.70	1.58	1.56	1.35	1.18	0.72
TEFLON	1.81	1.75	1.59	1.56	1.39	1.22	0.79
CONTROL	1.78	1.74	1.65	1.69	1.64	1.52	1.34
CONTROL	1.78	1.75	1.67	1.71	1.67	1.53	1.34
CONTROL	1.81	1.78	1.70	0.34	1.71	1.57	1.57

Table A20. Concentration of ODCB with time--salt study.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1200hr
SS304	2.48	2.42	2.32	2.32	2.34	2.25	1.86
SS304	2.46	2.43	2.32	2.33	2.37	2.28	1.90
SS304	2.49	2.46	2.25	2.34	2.15	2.15	2.20
SS316	2.48	2.36	2.28	2.11	2.26	2.16	1.92
SS316	2.46	2.38	2.32	2.40	2.31	2.16	2.03
SS316	2.49	2.40	2.34	2.42	2.36	2.23	1.88
PVC	2.48	2.44	2.28	2.05	2.21	2.04	1.64
PVC	2.46	2.43	2.33	2.31	2.28	2.09	1.57
PVC	2.49	2.39	2.35	2.29	2.15	2.10	1.61
TEFLON	2.48	2.29	2.14	2.03	1.78	1.54	0.73
TEFLON	2.46	2.27	2.14	2.12	1.69	1.57	0.87
TEFLON	2.49	2.33	2.11	2.13	1.88	1.62	0.90
CONTROL	2.48	2.40	2.32	2.35	2.31	2.24	2.18
CONTROL	2.46	2.42	2.28	2.39	2.37	2.20	1.94
CONTROL	2.49	2.45	2.33	2.45	2.42	2.21	1.94

Table A21. Concentration of MDCB with time--salt study.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1200hr
SS304	2.49	2.40	2.29	2.28	2.28	2.18	2.05
SS304	2.48	2.42	2.20	2.28	2.31	2.21	1.70
SS304	2.49	2.46	2.32	2.31	2.04	2.06	1.64
SS316	2.49	2.38	2.29	2.30	2.23	2.15	1.77
SS316	2.48	2.33	2.32	2.37	2.16	2.07	1.88
SS316	2.49	2.36	2.23	1.98	2.33	2.06	1.67
PVC	2.49	2.40	2.25	1.90	2.20	1.88	1.28
PVC	2.48	2.38	2.31	2.18	2.10	1.96	1.35
PVC	2.49	2.44	2.29	2.21	2.05	1.97	1.39
TEFLON	2.49	2.21	1.95	1.79	1.48	1.09	0.39
TEFLON	2.48	2.25	2.00	1.85	1.38	1.12	0.55
TEFLON	2.49	2.31	1.98	1.86	1.30	1.17	0.50
CONTROL	2.49	2.37	2.25	2.31	2.31	2.12	2.01
CONTROL	2.48	2.40	2.32	2.36	2.36	2.12	1.73
CONTROL	2.49	2.44	2.28	2.43	2.29	2.16	1.73

Table A22. Concentration of PDCB with time--salt study.

Concentration mg/L

treatment	0hr	1hr	8hr	24hr	72hr	168hr	1200hr
SS304	2.09	2.07	2.00	1.96	1.95	1.86	1.79
SS304	2.09	2.09	1.92	1.96	1.97	1.75	1.48
SS304	2.11	2.09	1.98	1.97	1.74	1.87	1.45
SS316	2.09	2.05	2.00	1.98	2.01	1.82	1.54
SS316	2.09	2.04	1.94	2.03	1.92	1.77	1.64
SS316	2.11	2.02	2.01	2.08	1.85	1.76	1.47
PVC	2.09	2.05	1.94	1.86	1.88	1.60	1.14
PVC	2.09	2.07	1.99	1.91	1.79	1.66	1.18
PVC	2.11	2.06	2.00	2.03	1.73	1.66	1.19
TEFLON	2.09	1.91	1.72	1.51	1.09	0.93	0.34
TEFLON	2.09	1.95	1.70	1.58	1.16	0.97	0.43
TEFLON	2.11	1.99	1.68	1.58	1.25	0.89	0.47
CONTROL	2.09	2.03	2.01	2.08	1.96	1.80	1.76
CONTROL	2.09	2.08	1.96	1.86	1.97	1.80	1.53
CONTROL	2.11	2.09	1.98	1.96	2.03	1.84	1.52

Table A23. Normalized[1] concentrations of analytes taken from samples containing salt.

Analyte	Treatment	1 Hour	8 Hour	24 Hour	72 Hour	168 Hour	1000 Hour
RDX	Teflon	1.01	0.96	1.00	1.00	1.00	0.99
	PVC	1.01	1.00	0.92	0.99	1.00	1.00
	SS304	1.02	1.00	0.92	1.02	1.00	0.98
	SS316	1.13	1.00	1.01	1.02	1.00	0.99
TNB	Teflon	1.01	0.99	1.00	1.04	1.00	0.99
	PVC	1.01	1.01	0.94	1.01	1.00	0.98
	SS304	1.01	0.99	0.93	1.01	0.99	0.98
	SS316	1.09	0.99	1.00	1.02	0.99	0.96*
CDCE	Teflon	0.99	0.98	0.96*	0.88*	0.92*	0.83*
	PVC	1.01	1.01	0.95*	0.96	0.97	0.88
	SS304	1.01	1.00	0.98	0.97	1.00	1.03
	SS316	0.98	1.00	0.98	0.98	0.99	1.03
TDCE	Teflon	0.97*	0.94*	0.88*	0.74*	0.75*	0.60*
	PVC	1.00	1.00	0.94*	0.94	0.94	0.78
	SS304	1.01	0.99	0.98	0.96	1.01	1.06
	SS316	0.98	1.00	0.99	0.98	0.99	1.08
MNT	Teflon	0.99	0.98*	0.98	0.96*	0.97	0.88*
	PVC	1.00	1.01	0.98	0.97*	0.99	0.92*
	SS304	1.01	1.00	0.98	0.98	1.00	0.98
	SS316	1.00	1.00	1.01	0.98	1.00	0.96
TCE	Teflon	0.96*	0.92*	0.85**	0.69*	0.67*	0.42*
	PVC	1.01	1.00	0.95*	0.95	0.96	0.83
	SS304	1.02	0.99	0.97	0.96	1.01	1.06
	SS316	0.98	1.00	0.99	0.98	0.99	1.01
CLB	Teflon	0.97*	0.94*	0.91	0.78	0.77	0.51*
	PVC	1.00	1.01	0.91	0.94	0.95	0.83*
	SS304	1.01	1.00	0.98	0.97	1.00	1.02
	SS316	0.98	1.00	0.96	0.98	0.99	1.00
ODCB	Teflon	0.95*	0.92*	0.87*	0.75*	0.71*	0.41*
	PVC	1.00	1.00	0.92	0.94*	0.94*	0.80*
	SS304	1.01	0.99	0.99	0.97	1.00	0.98
	SS316	0.98	1.00	0.96	0.98	0.98	0.96
PDCB	Teflon	0.94	0.86	0.79*	0.59*	0.51*	0.26*
	PVC	1.00	1.00	0.98	0.91*	0.91*	0.73*
	SS304	1.01	0.99	1.00	0.95	1.01	0.98
	SS316	0.98	1.00	1.03	0.97	0.98	0.97
MDCB	Teflon	0.94*	0.87*	0.77*	0.56*	0.53*	0.26*
	PVC	1.00	1.00	0.89*	0.91*	0.91*	0.74*
	SS304	1.01	0.99	0.94	0.95	1.01	0.99
	SS316	0.98	1.00	0.97	0.97	0.98	0.97

[1] The values given here are determined by dividing the mean concentration of a given analyte at a given time and for a particular well casing by the mean concentration (for the same analyte) of the control samples taken at the same time.

Table A24. Regression analysis for samples containing Teflon casings (vs K_{ow}).

Regression Analysis -- Linear model: Y = a+bX

Dependent variable: Normalized conc. with tef   Independent variable: Kow

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	1.1789	0.148297	7.94958	.00005
Slope	-0.252084	0.061157	-4.12191	.00334

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	.502285	1	.502285	16.99017	.00334
Error	.2365063	8	.0295633		
Total (Corr.)	.7387916	9			

Correlation Coefficient = -0.824545   R-squared = 67.99 percent
Stnd. Error of Est. = 0.17194

Table A25. Regression analysis for samples containing PVC casings (vs K_{ow}).

Regression Analysis -- Linear model: Y = a+bX

Dependent variable: Normalized conc. with pvc   Independent variable: Kow

Parameter	Estimate	Standard Error	T Value	Prob. Level
Intercept	1.01749	0.0440471	23.1001	.00000
Slope	-0.0581521	0.0181648	- 3.20136	.01259

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	Prob. Level
Model	.026729	1	.026729	10.24874	.01259
Error	.0208646	8	.0026081		
Total (Corr.)	.0475941	9			

Correlation Coefficient = -0.749409   R-squared = 56.16 percent
Stnd. Error of Est. = 0.0510693

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Evaluation of four well casing materials for monitoring selected trace level organics in ground water / by Louise V. Parker, Thomas F. Jenkins and Patrick B. Black. Hanover, N.H.: U.S. Army Cold Regions Research and Engineering Laboratory; Springfield, Va.: available from National Technical Information Service, 1989.

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